# Techno-economic feasibility of conservation agriculture in rainfed regions of India

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*This article examines the potential of conservation agriculture (CA) in rainfed areas particularly in the arid and semi-arid regions of the Indian subcontinent. The CA practices under different types of rainfall, soil and production system were identified based on the analysis of studies undertaken in different agro-climatic regions of India. The net benefits from different suggested CA practices were estimated at current prices for the year 2010 based on the results of long-term experiments conducted at the Central Research Institute for Dryland Agriculture, Hyderabad, India and centres of its All-India Coordinated Research Project on Dryland Agriculture, which ranged from Rs 325 to 18,000 ha$^{-1}$. The capital requirement of various CA practices was also estimated. The analysis shows that CA in its broader context not only improves soil health but also gives higher net returns per unit of land to the farmers. However, the CA practices need to be adopted selectively in different rainfall, soils and agro-ecological situations. The advantage of CA practices can be availed in rainfed agro-ecology, if practised appropriately over long-term basis. Higher carbon sequestration through CA practices may also give additional benefits in terms of carbon emission reduction, if made easily tradable in future. However, for promotion of CA practices across diverse agro-ecologies, appropriate policy, and institutional and technology support would be a prerequisite.*

**Keywords:** Carbon sequestration, conservation agriculture, net benefits, rainfed regions.

CONSERVATION agriculture (CA) is generally referred to a way of practising agriculture that primarily includes low tillage, incorporation of crop residues and follow-up of better crop rotations[1]. However, there are many other management practices that qualify the definition of CA. The Food and Agriculture Organization (FAO), Rome, Italy defined the concept as ‘resource saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment’[2]. Tillage interventions are reduced to the bare minimum besides low external inputs which will lead to better biological processes in the soil. The widely practised CA in terms of minimum/zero tillage, viz. zero/low tillage is predominant in South America (47%), the United States and Canada (39%), Australia (9%) and the rest elsewhere. In the Indian context, CA is popular in the rice–wheat system in the Indo-Gangetic Plains (IGP) and of late is getting popular in the Deccan Plateau in the rice–rice system with the second crop of rice getting replaced by maize.

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Rainfed or dryland agriculture is prominent in India, accounting for about 56% of the total cropped area and contributes 87.5% coarse cereals, 87.5% pulses, 77% oilseeds and 65.7% cotton of the country’s total production. The rainfed lands are also the areas that are prone to the ill-effects of climate change and experience hardships like drought and frequent crop failures. Further, the Indian climate, which is predominantly tropical and subtropical, encourages degradation of the land mass. In fact, the rainfed regions, especially arid and semi-arid areas particularly represented by Alfisols, Aridisols and related soil groups are characterized by light texture, low organic carbon and low depth soils and low moisture, erratic rainfall, soil erosion and low use of fertilizer due to poor income levels and low productivity. Other soil groups such as Vertisols and Inceptisols also experience diversity of soil-related constraints. CA practices are likely to address the above constraints, if adopted on a long-term basis. It is therefore important to evaluate the feasibility and potential of CA in rainfed regions. While for developed economies like USA, saving the surface soils might be the prime drive for adoption of CA, for the developing economies, beside protecting the lands, other additional emerging agrarian concerns like shortage of water, labour and energy, deteriorating soil health and climate change are also important.

Given the large area under rainfed agriculture which is associated with poor soils, low cropping intensity and low productivity, it would be interesting to analyse the techno-economic feasibility of different CA practices in these areas. This article attempts to expand the scope of CA practices besides identifying the rainfed tracts and production systems that would provide the opportunity for CA adoption. The net benefits due to CA practices compared to the existing agricultural practices and corresponding capital requirement have also been assessed.

## Materials and methods

The article mainly draws on the past studies and relies on the experiments conducted in rainfed areas. Moreover, identification of CA practices under different rainfall and soil situations in rainfed regions has been done through an analysis of studies undertaken and a brainstorming session involving experts working in the area of CA. For the purpose of evaluating the potential, reasonable assumptions have been made besides published work. The major cropping season during rainy months from June to October–November, in rainfed regions of India is called kharif season, and the other cropping season is the rabi season which falls during winter months from October–November to February–March. Crop cultivation in semi-arid and arid rainfed regions during summer months from March to June is hardly possible due to non-availability of moisture.

The term CA which has been defined by FAO as resource conservation agricultural crop production may be expanded in the local context for rainfed regions in the Indian subcontinent. Conservation of soil and water besides practices that contribute towards improving soil health and its productive capacity must form the major components of CA in rainfed regions. Hence, the practices of *in situ* moisture conservation such as contour/field bunding, conservation furrows, ridge and furrow, continuous contour trenches, water absorption trenches, percolation tanks, water harvesting through farm ponds, energy-saving during water lifting and reclying, check dams, minimum tillage, zero tillage, cover crops/residue application, agroforestry, vegetative cover for uncultivated lands, introduction of perennial species along with seasonal crops, organic farming, crop rotations and integrated nutrient management (INM) may form the components of CA.

In order to ascertain techno-economic feasibility of CA in rainfed areas, the practices that are appropriate/recommended across rainfalls, soil types and production systems were identified based on the analysis of studies undertaken at the Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad, India and network centres of its All-India Coordinated Research Project on Dryland Agriculture (AICRPDA) over the past 30 years, as well as a brainstorming session involving scientists working on themes related to CA. Further, the net economic benefits of adopting CA practices were estimated at current prices based on the results of long-term experiments conducted at CRIDA and AICRPDA centres and their Operational Research Projects (ORPs) in different agro-climatic zones. The requirement of capital for related implements and creating structures was also estimated. Technology, policy and institutional needs were assessed through a brainstorming session.

## Results and discussion

### *Extent of land degradation*

Degradation of land – both arable and non-arable – is a phenomenon influenced by natural weathering and human interventions. Of late, the latter is adding to the degradation at a faster pace than the former. In the context of conserving the land for agriculture and livelihood, it is necessary to comprehend the extent of degradation across the geo-political regions. Among the states (proviences) in India, Jammu & Kashmir and Nagaland have maximum share of their land (94%) under degradation (Table 1). This is primarily due to large areas under mountains, cold deserts and other such degraded lands. In the agriculturally prominent states like Uttar Pradesh (63%), Madhya Pradesh (50%) and Karnataka (46%), the extent of land degradation is of great concern. Ecological agriculture either through CA or any other form will help check land degradation. Rainfed areas which have greater need of CA are spread across different states of India.

Among the states, the extent of rainfed area to the total cultivated area is the highest in Jharkhand (91%) followed by Maharashtra (81%) and Chhattisgarh (74%). On the other hand, agriculturally important states in the Deccan Plateau like Andhra Pradesh and Karnataka have 53% and 71% area under rainfed agriculture respectively. Land degradation in the country is posing a big threat to the natural resources, resulting in almost 5 billion tonnes soil and 6 million tonnes of nutrient loss every year[3]. The loss of precious topsoil is comparatively much more in dryland areas because of low moisture and poor soil covering vegetation and residues. It is a common phenomenon in the Indian subcontinent where the water bodies get clogged and chocked with silt, which is mainly the sediment coming along with the run-off. Economically, the topsoil loss not only deprives the production, but also adds to the cost of desilting of the water bodies. The cost of such loss has been estimated to be Rs 500/ha (ref. 4). Hence, protection of the top soil, especially in rainfed regions is most crucial for sustainable agricultural production.

**Table 1.** Area under degraded land across major states of India

| State/province | Degraded land (ha) | Geographical area (ha) | Degraded land (%) |
|---|---|---|---|
| Andhra Pradesh | 10,306,989 | 27,506,544 | 37 |
| Arunachal Pradesh | 3,391,291 | 8,374,215 | 40 |
| Assam | 4,642,071 | 7,843,860 | 59 |
| Bihar | 1,659,322 | 9,416,395 | 18 |
| Chhattisgarh | 4,947,419 | 13,518,883 | 37 |
| Gujarat | 3,350,636 | 19,612,517 | 17 |
| Haryana | 582,307 | 4,421,858 | 13 |
| Himachal Pradesh | 2,946,569 | 5,567,137 | 53 |
| Jammu & Kashmir | 20,856,943 | 22,223,695 | 94 |
| Jharkhand | 4,290,431 | 7,971,624 | 54 |
| Karnataka | 8,740,358 | 19,179,155 | 46 |
| Kerala | 2,599,450 | 3,886,749 | 67 |
| Madhya Pradesh | 15,338,850 | 30,824,985 | 50 |
| Maharashtra | 10,837,506 | 30,758,377 | 35 |
| Orissa | 5,024,846 | 15,570,900 | 32 |
| Punjab | 552,733 | 5,036,513 | 11 |
| Rajasthan | 21,013,097 | 34,224,212 | 61 |
| Tamil Nadu | 3,850,948 | 13,005,861 | 30 |
| Uttar Pradesh | 15,270,634 | 24,092,803 | 63 |
| Uttarakhand | 3,215,069 | 5,348,204 | 60 |
| West Bengal | 2,237,615 | 8,875,874 | 25 |
| India | 154,553,121 | 327,869,491 | 47 |

Source: National Remote Sensing Centre dataset, unpublished.

## *Conservation agriculture in the context of rainfed areas*

Unlike largely homogenous growing environments of IGP, the production systems in rainfed arid and semi-arid areas are quite heterogeneous and diverse with respect to the management of land, water and cropping systems. The rainfed cropping systems are mostly single-cropped in the red soil areas, whereas in the black soil regions a second crop is taken on the residual moisture. In black soils, farmers (agriculture producers) keep lands fallow also during kharif and grow rabi crops on conserved moisture. The rainfall ranges from < 500 mm in arid to 1000 mm in dry sub-humid areas. Alfisols, Vertisols, Inceptisols, Entisols and Oxisols are the major soil orders. Soils are sloppy and highly degraded due to continuous erosion by water and wind. Sealing, crusting, sub-surface hard pans and cracking are the key factors which cause high erosion and impede infiltration of rainfall. The choice and type of tillage largely depend on the soil type and rainfall. Leaving crop residue on the surface is another important component of CA, but in rainfed areas due to its competing uses as fodder, little or no residues are available for surface application.

The key principles of rainfed agriculture rely on soil and water conservation which are integral components of CA. Though conserving both soil and water are equally important in low to medium rainfall regions, more priority is given for conservation of rainwater by facilitating better infiltration and reduced run-off. That is why deep tillage once in three years is suggested to promote greater infiltration of rainwater and to control weeds. However, practices like chiselling can meet the objective of breaking the hard pan without soil inversion associated with deep tillage. Experience from several experiments in the country showed that minimum or reduced tillage does not offer much advantage over conventional tillage in terms of grain yield without maintenance of adequate amount of residue on the surface[5]. Leaving surface residue is the key to control run-off, soil erosion and hard setting in rainfed areas, which are the key problems. In view of the shortage of residues in rainfed areas in arid and semi-arid regions, several alternative strategies have emerged for generation of residues either through *in situ* cultivation and incorporation as a cover crop or harvesting from perennial plants grown on bunds and adding the green leaves as manure cum mulch. Agroforestry and alley cropping systems are other options where biomass generation can be integrated along with crop production. Thus, the concept of CA has to be understood in a broader perspective in arid and semi-arid areas, which includes an array of practices like reduced tillage, land treatments for *in situ* and *ex situ* water conservation, on-farm and off-farm biomass generation and alternate land-use systems and also the energy conservation. Here, reduced or minimum tillage with residue retention on the surface, which is also called conservation tillage, is more appropriate than zero tillage which is emphasized in irrigated agriculture[6].

Under semi-arid conditions at Hyderabad, summer tillage helped in higher soil moisture retention by 20%, reduced weed infestation by 40% and contributed to higher yields (Table 2). Similarly, at Jodhpur, pearl millet yielded higher under conventional tillage compared to zero tillage (Table 3). Even after the eighth year of the study, conventional tillage remained superior to minimum tillage, which could be attributed to more weed growth and less infiltration of water due to compaction of the surface soil under minimum tillage (Table 4). In this case, the surface residue applied @ 2 tonne $ha^{-1}$ was just inadequate to create the desirable soil ameliorative effect. It is anticipated that, if residue levels are enhanced, the beneficial effect of minimum tillage could be seen over the years[7].

The studies so far conducted in dryland areas[5,7–11] have shown that conventional tillage gives higher yields compared to zero tillage. However conservation tillage along with mulching with residues and INM gave significantly higher net returns in cotton in central India[12]. Conservation tillage with residue mulching is important for restoring and improving the soil health which is necessary for sustainable agricultural production. Besides conservation tillage, a number of practices, viz. intercropping systems with pulse, soil and water conservation techniques, water harvesting and recycling, selective mechanization and alternate land-use systems have similar resource conservation effects like CA. As most of the dry lands are single-cropped regions, the length of the growing period is around 4–6 months, setting aside 6–8 months as the off-season, allowing land to be barren and exposed to weathering and soil loss. Therefore, it is imperative that some vegetation or stubbles are maintained on the soil to prevent such weathering. The potential of such measures is high in sub-humid and humid regions where the stubbles have greater chance of remaining in the same soil[13].

## *Carbon sequestration potential*

Generally, the rainfed soils are miserably low in organic carbon (OC) and are starved of nutrients. In majority of the rainfed lands, OC is in the range 0.3–0.6% on weight basis[14]. Low OC is one of the major reasons for poor fertility of soils in rainfed regions, especially Alfisols (red soils). Carbon storage not only improves fertility and productivity of soils, but also abets global warming. Next to the forests, agriculture lands with better management have great potential for sequestering carbon. CA has one of the benefits in the form of carbon sequestration, especially through alternate land-use systems. The benefits of such carbon sequestration through market participation can go to the individuals as well as to the local communities. It has been found that CA practices, viz. INM under different production systems in rainfed regions sequestered significantly higher carbon compared to farmers' practice and contribute to soil health improvement and sustainability of the system (Table 5). These suggested CA (INM) practices would also accrue carbon credits equivalent to carbon emission reduction (CER) valuing from US$ 0.71 to 2.79 per ha, which are likely to get higher market value in the future. If CERs generated from small-scale agriculture are made easily tradable, these practices would generate additional returns for the farmers. In the present scenario, the availability of organic resources for agriculture such as farm yard manure, compost, etc. in India is considered highly scarce. However, it has been estimated that there is a potential to produce 6.24 million tonnes of N + P + K through organic resources, if harnessed properly (Table 6).

**Table 2.** Effect of off-season tillage on grain yields of sorghum and castor in Alfisols of Hyderabad[8]

| Practice | Sorghum grain yield* (tonne/ha) | Castor bean** (tonne/ha) |
|---|---|---|
| Without off-season tillage | 1.87 | 0.32 |
| With off-season tillage | 2.60 | 0.31 |

*Mean of three seasons; **Mean of two seasons.

**Table 3.** Yield of pearl millet under conventional and no tillage conditions in the arid regions at Jodhpur[9]

| | Pearl millet yield (q/ha) | |
|---|---|---|
| Year | Conventional tillage | No tillage |
| 1995 | 6.48 | 5.84 |
| 1996 | 9.09 | 2.26 |
| 1977 | 7.14 | 2.26 |
| 1998 | 3.83 | – |

## *CA practices for rainfed production systems and their potential benefits*

Based on the long-term experimental data and review of studies across the arid, semi-arid and sub-humid regions undertaken over the past 30 years[7,9,10,14,15,17,18], CA practices were identified for different types of rainfalls, soil and production system. Net benefits of using different CA practices over the farmer practices and associated capital costs under different production systems were estimated at current prices for 2010 (Table 7). To promote CA practices at the field level, it would be prudent to have convergence with on-going agriculture and rural development schemes of the Government of India (GoI) like: MNREGS (Mahatma Gandhi National Rural Employment Guarantee Scheme) which is a wage-creation programme of the GoI for rural poor mainly by undertaking natural resources management works in rural areas and it guarantees 100 days of employment to every rural wage seeker; NHM (National Horticulture Mission) that provides technical and infrastructure support to the farmers for development of horticulture in India; RKVY (Rashtriya Krishi Vikas Yojana) which supports rural and agricultural activities in backward districts in India; NFSM (National Food Security Mission) that undertakes programmes to augment food production in economically backward and

**Table 4.** Long-term effects of tillage and residue application on crop yield and sustainable yield index (8 years)[7]

| Residue | Sorghum (kg/ha) | | Castor (kg/ha) | | Sustainability yield index | |
|---|---|---|---|---|---|---|
| | Conventional tillage | Minimum tillage | Conventional tillage | Minimum tillage | Conventional tillage | Minimum tillage |
| Sorghum | 1127 | 810 | 820 | 477 | 0.49 | 0.35 |
| *Gliricidia* loppings | 1201 | 895 | 925 | 507 | 0.50 | 0.37 |
| No residue | 1103 | 840 | 840 | 448 | 0.48 | 0.31 |
| Mean | 1144 | 848 | 862 | 477 | 0.49 | 0.34 |
| Tillage ($T$) | ** | ** | * | | | |
| Residue ($R$) | ** | ** | * | | | |
| $T \times R$ | NS | NS | NS | | | |

*Significant at $P = 0.05$; **Significant at $P = 0.01$; NS, Non-significant at $P > 0.05$.

**Table 5.** Carbon sequestration rate in soil (0–20 cm) and potential carbon emission reduction (CER) under different conservation agriculture (CA) practices based on data from long-term experiments[15]

| Production system (soil type/order) | Suggested CA practice | Carbon sequestration (t ha$^{-1}$) | | Potential CER from suggested CA practice | |
|---|---|---|---|---|---|
| | | Farmer practice | Suggested CA practice | t ha$^{-1}$ | Value (US $) |
| Groundnut-based (in Alfisols) | 50% RDF + 4 t groundnut shell ha$^{-1}$ | 0.08 | 0.45 | 0.370 | 1.85 |
| Groundnut–finger millet (in Alfisols) | FYM 10 t + 100% RDF (NPK) | –0.138 | 0.241 | 0.379 | 1.90 |
| Finger millet–finger millet (in Alfisols) | FYM 10 t + 100% RDF (NPK) | 0.046 | 0.378 | 0.332 | 1.66 |
| Sorghum-based (in Vertisols) | 25 kg N (FYM) + 25 kg N (urea) | 0.101 | 0.288 | 0.187 | 0.94 |
| Soybean-based (in Vertisols) | 6 t FYM ha$^{-1}$ + 20 kg N + 13 kg P | –0.219 | 0.338 | 0.557 | 2.79 |
| Rice-based (in Inceptisols) | 100% organic (FYM) | –0.014 | 0.128 | 0.142 | 0.71 |
| Pearl millet-based (in Aridisols) | 50% N (inorganic fertilizer) + 50% N (FYM) | –0.252 | –0.110 | 0.142 | 0.71 |

CER @ US$ 5 t$^{-1}$ (prevailing market price of CER for agroforestry and other related practices); RDF, Recommended dose of fertilizer; FYM, Farm yard manure.

**Table 6.** Potential of organic resources for agricultural use in India during 2000–2025 (ref. 16)

| Resource | Year | | |
|---|---|---|---|
| | 2000 | 2010 | 2025 |
| Generators | | | |
| Human population (million) | 1000 | 1120 | 1300 |
| Nutrients (theoretical potential) – 1 | | | |
| Human excreta (million tonnes N + $P_2O_5$ + $K_2O$) | 2.00 | 2.24 | 2.60 |
| Livestock dung (million tonnes N + $P_2O_5$ + $K_2O$) | 6.64 | 7.00 | 7.54 |
| Crop residues (million tonnes N + $P_2O_5$ + $K_2O$) | 6.21 | 7.10 | 20.27 |
| Nutrients (considered tappable) – 2 | | | |
| Human excreta (million tonnes N + $P_2O_5$ + $K_2O$) | 1.60 | 1.80 | 2.10 |
| Livestock dung (million tonnes N + $P_2O_5$ + $K_2O$) | 2.00 | 2.10 | 2.26 |
| Crop residues (million tonnes N + $P_2O_5$ + $K_2O$) | 2.05 | 2.34 | 3.39 |
| Total | 5.05 | 6.24 | 7.75 |

Note: Tappable organic resources = 30% of dung, 80% of excreta, 33% of crop residues.

less productive areas of India and Integrated Watershed Development Programme that supports integrated agricultural development on watershed basis.

The analysis clearly demonstrates that the suggested CA practices, viz. rainwater harvesting and recycling for supplemental/critical/irrigation, recharging of open wells/borewells for efficient recycling, location-specific interterrace land management, *in situ* moisture conservation, INM and balanced nutrition, seed-cum-fertilizer drill, alternate land use with efficient agroforestry systems, reduced tillage with residue mulching and chemical weed control for various production systems in different soil

**Table 7.** Suggested CA practices and their potential benefits under different production systems in rainfed regions

| Rainfall (mm) | Major soil types/order | State | Major production systems | Suggested CA practice | Potential benefits: Increment in the yield of the system (%) | Potential benefits: Additional net returns to fixed farm resources (Rs $ha^{-1}$ $annum^{-1}$) | Capital requirement for technology adoption: Unit cost of implement/ structure (Rs) | Capital requirement for technology adoption: Life of the implement/ structure (year) | Capital requirement for technology adoption: Area covered by one unit (ha) |
|---|---|---|---|---|---|---|---|---|---|
| < 500 | Aridisols | Haryana and Rajasthan | Pearl millet-based | Conservation tillage (and sowing) with ridger seeder. Implement: Ridger seeder | 23 | 1400 | 45,000 | 5 | 10 |
| | | | | INM in pearl millet. | 14–20 | 535–750 | – | – | – |
| | | | | Use of bullock-drawn blade hoe for soil mulch creation and weed control. | 12 | 325 | 3000 | 5 | 1 |
| 500–750 | Alfisols | Andhra Pradesh | Sorghum, castor-based | Formation of conservation furrow in castor. | 30 | 2100 | 48,000 | 5 | 20 |
| | | | | INM by conjunctive use of fertilizers + green biomass of N-fixing trees such as *Glyricidia*; N use of compost + fertilizers (50 : 50%). | 15 | 1200 | – | – | – |
| | | | | Water harvesting and recycling through farm ponds (initial capital to be given by the government through NREGS, RKVY). (250 $m^3$ farm pond with lining + sprinkler with 3 hp pump set.) | 15–25 (increase in cropped area 10–15%) | 4500–7400 per farm pond/annum | 55,000 | 10 | Viable for farm size of > 1.5 ha |
| | | | Groundnut, castor-based | Application of groundnut shell @ 5 t/ha after 10 days of sowing in groundnut. | 10–15 | 2200–3500 | – | – | – |
| | | | | Water harvesting and recycling through farm ponds with lining with soil + cement (6 : 1 ratio) – convergence with NREGS, RKVY. (250 $m^3$ Farm pond with lining + sprinkler with 3 hp pump set.) | 20–24 Diversification into vegetables | 3850–6500 | 55,000 | 10 | One per farm holding |
| | | | | Use of rhizobium @ 500 g/ha + 20–40–40 N, $P_2O_5$ and $K_2O$ in groundnut. | 20 | 1800 | – | – | – |
| | Inceptisols | Rajasthan | Maize-based | Early rabi cropping of chickpea under Nadi system of water harvesting. (Conserves soil, higher use efficiency of harvested rainwater.) | 30–35 | 2500–3200 | Rs 25 per $m^3$ for existing Nadis | 4 | 2 $m^3$ per ha |
| | | | | Water harvesting and recycling through farm ponds with lining – convergence with NREGS, RKVY. (500 $m^3$ farm pond with lining + sprinkler with 3 hp pump set.) | 20–25 Diversification + bringing waste-land into cultivation | 8,500–12,000 | 75,000 | 10 | One per farm holding (for farms of > 2 ha) |
| | Vertisols | Gujarat | Groundnut-based | Set row planting of groundnut. (Conserves soil and saves seed, fertilizer, labour.) | 15 | 2800 | – | – | – |

(*Contd*)

**Table 7.** (*Contd*)

| Rainfall (mm) | Major soil types/order | State | Major production systems | Suggested CA practice | Potential benefits: Increment in the yield of the system (%) | Potential benefits: Additional net returns to fixed farm resources (Rs $ha^{-1}$ $annum^{-1}$) | Capital requirement for technology adoption: Unit cost of implement/ structure (Rs) | Capital requirement for technology adoption: Life of the implement/ structure (year) | Capital requirement for technology adoption: Area covered by one unit (ha) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Use of enriched compost (6 t $ha^{-1}$). | 15–23 | 1600–2700 | – | – | – |
| | | | | Recharging defunct open wells through filters. (Retains 67% sediment load and enhances ground water level.) | 15–30 | 1400–2500 | 50,000 | 8 | 2 |
| | | | | Filter and deepening of the defunct well. | | | | | |
| | | Tamil Nadu | Cotton-based | Compartmental bunding and balanced nutrition in rainfed cotton. | 20–28 | 2000–3200 | – | – | – |
| | | Maharashtra | Rabi, sorghum-based | Compartmental bunding in rabi sorghum. | 15–20 | 1500–2100 | – | – | – |
| | | | | Ridge and furrow for *in situ* moisture conservation. (Conserves 45% more moisture.) Implement: Tractor-drawn ridge maker | 15–30 | 1400–3000 | 20,000 | 5 | 5 |
| | | | | Two-bowl ferti-seed drill for efficient sowing of rainfed crops. (Higher nutrient use efficiency, labour saving.) | 20–25 | 1500–2200 | 22,000 | 5 | 5 |
| | | | | 50% N through crop residue (sorghum/Leucaena) + 50% N through fertilizer to rabi/sorghum. | 20 | 1400–1500 | – | – | – |
| | | Karnataka | Rabi, sorghum-based | Compartmental bunding. | 30–40 | 4500–7500 | – | – | – |
| | | | | Cover cropping with pulse crops. | | | | | |
| | | | | (Conserves soil and water, improves soil quality.) | 20–25 | 2200–3000 | – | – | – |
| | | | | Inter plot rainwater harvesting. | 25 | 10,000–15,000 | 90,000 | 10 | 1 |
| | Entisol | Uttar Pradesh | Pearl millet, mustard-based | Ridge planting of pearl millet. | 20–30 | 2200–3000 | 42,000 | 5 | 10 |
| | | | | INM through 50% fertilizer N + 50% FYM N. | 20 | 1500 | – | – | – |
| | Aridisol | Gujarat | Castor, pearl millet-based | Compartmental bunding in pearl millet. | 20 | 500–800 | – | – | – |
| | | | | Silvi-pasture system (amla + *Dichanthium annulatum*). (Conserves soil and water, improves soil quality, higher carbon sequestration, supply fodder.) | 15–20 as compared to sole Amla | 4500–5500 | – | – | – |
| 750–1000 | Alfisol | Karnataka | Finger millet-based | Rainwater harvesting and recycling through lined farm pond. (Initial capital to be given by the government through NREGS, RKVY, etc.) (250 $m^3$ Farm pond with lining + sprinkler with 3 hp pump set.) | 15–20 (10–15% more area under vegetables) | 5,500–12,000 | 55,000 | 10 | 1.5 ha |
| | Vertisol | Madhya Pradesh | Soybean-based | Conservation tillage (and sowing of soybean) with ridger seeder. Implement: Ridger seeder. | 15–18 | 4500–5500 | 40,000 | 6 | 10 |
| | | | | Straightening of gullies to reduce their length. | 10 | 1000–1200 | 75 per $m^3$ | 5 | – |

(*Contd*)

**Table 7.** (*Contd*)

| Rainfall (mm) | Major soil types/order | State | Major production systems | Suggested CA practice | Potential benefits: Increment in the yield of the system (%) | Potential benefits: Additional net returns to fixed farm resources (Rs $ha^{-1}$ $annum^{-1}$) | Capital requirement for technology adoption: Unit cost of implement/ structure (Rs) | Capital requirement for technology adoption: Life of the implement/ structure (year) | Capital requirement for technology adoption: Area covered by one unit (ha) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Water harvesting through ponds (initial capital to be given by the government through NREGS, RKVY, etc.). (1000–4000 $m^3$ pond without lining mainly for large farmers.) | 20–40 (Diversification into flori-horticulture) | 10,000–25,000 per pond of 1000 $m^3$ | 75 per $m^3$ | 8 | – |
| | | Maharashtra | Cotton-based | Rainwater harvesting and recycling through farm ponds. (Initial capital may be arranged through schemes like NREGS, RKVY, etc.) (500 $m^3$ farm pond without lining + sprinkler with 3 hp pump set.) | 20–25 (+15–20% increase in cropped area + aquaculture) | 8,000–16,000 per pond | 75,000 | 8 | > 2 ha farms |
| | | | | *In situ* moisture conservation through top sequence-based cropping. (Conserves soil, water and saves energy, reduces tillage.) | 20–25 | 4,000–5,000 | – | – | – |
| | | | | *In situ* incorporation of crop residues through Rotavator. (At 12–14% moisture in field.) | 5–20 | 2,000–12,000 | 85,000 | 10 | 15 |
| | | | | Application of 5 tonne of FYM + 40 kg $P_2O_5$ + microbial culture @ 1.5 kg/ha to pigeonpea. | 25 | 3200 | – | – | – |
| | Inceptisols | Uttar Pradesh, Bihar | Paddy-based | Power-operated till planting for sowing of crops in rice fallows. (Reduces tillage, uses residual moisture, saves time.) | 15–19 | 6,000–7,500 | 110,000 | 8 | 10 |
| > 1000 | Inceptisols | Jammu & Kashmir | Maize-based | Rainwater harvesting and recycling through farm pond. (250 $m^3$ Farm pond with lining + sprinkler with 3 hp pump set.) | 25 and diversification | 4,500–10,000 per pond | 50,000 | 10 | One land holding |
| | | Uttar Pradesh, Bihar | Paddy-based | Ridge and furrow system and diversification of rice–wheat cropping system into rice–pigeonpea system. (Cost reduction, improves soil health, conserves rainwater.) Bullock-drawn implement for small farmers. | 8–12 | 3,800–5,200 | 4000 | 5 | 1 |
| | Oxisols | Jharkhand | Paddy-based | Rainwater harvesting and recycling through farm pond. (Initial capital to be given by the government through NREGS, RKVY, etc.) Farm pond size: 1000–4000 $m^3$ with lining + sprinkler with 3 hp pump set. | 30–50 | 15,000–36,000 | 100,000–350,000 | 10 | 5 |
| | Vertisols | Madhya Pradesh | Paddy, soybean-based | Rainwater harvesting and recycling through farm pond. (Initial capital to be given by the government through NREGS, RKVY, etc.) (250–500 $m^3$ farm pond without lining + sprinkler with 3 hp pump set.) | 20–25 (Higher diversification) | 7,000–18,000 | 45,000–70,000 | 10 | One land holding |

Note: INM practice of applying 50% N through organic + 50% N through inorganic fertilizers is suggested for every production system.

**Table 8.** Conditions to be met for adoption of CA practices

| CA practices/interventions | Policy and institutional needs | Technology needs |
|---|---|---|
| Rainwater harvesting/farm ponds/well recharging | Initial investment has to come from the government by converging different schemes like MNREGS/RKVY/NFSM/watershed programmes, etc.<br>Operationalization of farm ponds needs to be done as a customized package for water harvesting and utilization (including inlet and outlet pitching and lining of the pond, water lifting, micro-irrigation system, etc.) | Low-cost and easy to handle water-lifting devices and micro-irrigation systems matching the needs of different categories of farmers need to be developed.<br>Farmers must be properly trained to handle and maintain micro-irrigation systems. |
| Integrated nutrient management (conjunctive use of organic and inorganic fertilizers, residue management, mulching through biomass) | Arrangements in place for capacity-building.<br>Policy favouring promotion of organic supply of nutrient in terms of crop residue management and higher biomass production for mulching, particularly in fragile soil environments.<br>Convergence with RKVY, NHM, etc. may be useful.<br>Making biomass shredder available on subsidy to encourage mulching through agricultural residues (non-edible for animals). Rotavator may be used for incorporation of residues in the soil. | Location-specific on-farm demonstrations on a large scale.<br>Develop and provide power-operated machine to shred the non-edible (as fodder) agricultural residues like cotton stalk to use them for mulching. |
| *In situ* moisture conservation | Identification of appropriate *in situ* moisture conservation practices (ISMCP) on agro-climatic zone basis and further narrowing down to district/sub-district level.<br>Need to be implemented as an area approach by converging with relevant programmes like NREGS/RKVY/watershed programme covering all categories of farmers cultivating marginal/fragile lands/soils.<br>Need to improve access to needed implements like ridge and furrow maker for wider scale adoption of ISMCPs through custom-hiring services promoted by self-help groups and/or subsidy. | Large-scale on-farm demonstrations.<br>Launching awareness campaign.<br>Appropriate implements (bullock-drawn/tractor-drawn) need to be identified/modified/ developed. |
| Alternate land-use systems (ALUS) – Silvi-agri, horti-agri and agroforestry systems | Capacity-building of the stakeholders.<br>Single-window delivery system of support for promoting ALUS starting from land preparation to the stage when ALUs begins to give economic benefits. Convergence among NREGS, NHM and watershed programme may help in this. | Delineate suitable areas for promoting ALUS considering local resources, traditional skills, market opportunities, fodder supply, carbon credits and value-addition options. |

and rainfall situations not only improve the productivity and sustainability of the system but also significantly enhance net returns per hectare over the existing farmer practice (Table 7). The additional net returns per hectare due to CA in different crops and regions ranged from Rs 325 to 18,000. Although in case of some of the CA practices as depicted in Table 7, the net benefits over the variable cost are just able to recover the initial capital cost, these resource conservation practices need to be seen in the broader context of enhancing sustainability of rainfed agriculture and livelihood security of small-holders in these regions. In fact, in the absence of implementation of CA practices, there is a danger of productivity loss in future in the rainfed regions.

## *Technology, policy and institutional needs*

In order to promote adoption of CA in rainfed regions in the Indian subcontinent, it would be necessary to put appropriate policy and institution arrangements in place and make suitable technological options available to the farmers. Many CA practices like rainwater harvesting through farm pond and its recycling are both capital and labour-intensive, which resource-poor farmers in rainfed areas may not be able to afford and hence need to be supported through capital subsidy. In a study of adoption of CA practices in ORPs under AICRPDA network centres[19], it was summarily inferred that non-adoption of CA practices/natural resource management technologies was mainly due to lack of proper institutional and policy support. Therefore, the following technology, policy and institutional arrangements may be put in place to promote CA practices (Table 8).

An effective institutional arrangement is required at the village level to promote CA or other innovations. In rainfed regions, where farmers are resource-poor and agricultural productivity is low, farmers' access to information related to technology, market, credit and government schemes and policies is poor. Hence, there is a need to improve the farmers' knowledge and access to information using information and communication technology and employing technically qualified and trained persons at the village level. Further to promote CA the following steps may be taken up:

- There is a need to create awareness among the communities about the importance of conservation of land/soil resources and organic matter build-up in the soil. Traditional practices such as burning of residues, clean cultivation, intensive tillage and pulverization of the soil up to the finest tilth need to be discouraged. Electronic media support at a large scale is a must to convey these aspects to the farmers/communities.
- At least the non-edible (for animals) agricultural residues must not be burnt and should be used for mulching. Agroforestry systems with special emphasis on silvipasture systems need to be introduced.
- For the adoption of conservation tillage, it is essential that a complete package of practices may be identified for each agro-ecological region.
- The increased use of herbicides has become inevitable for adopting conservation tillage/conservation farming practices. In order to reduce the herbicidal application, there is a need to improve crop husbandry practices that suppress weeds.
- Conservation farming also has the objective to minimize the inputs originating from non-renewable energy sources, e.g. fertilizers and pesticides. Hence, research focus is required on enhancing fertilizer use efficiency and reduction in the use of pesticides. This aspect can be strengthened by following INM and integrated pest management approaches.
- Inter-disciplinary research efforts are required to develop appropriate implements for seeding in zero tillage, residue incorporation and inter-cultural operations.
- Initially CA practices, especially zero/reduced tillage may result in reduced yields over conventional tillage, but catch up with the latter over time. Hence, initial incentives are important to motivate the farmers to follow conservation tillage.
- Improving soil quality through adoption of CA principles should be a priority, as protection of land resource is an investment for future. This aspect must form a part of the national agenda and priority in National Agricultural Policy. A National Mission on Conservation Agriculture akin to the National Horticulture Mission may be created in the XII Five-Year plan.

## Conclusion

The analysis shows that CA in its broader sense not only improves soil health and protects environment, but also gives higher net returns per unit of land to the farmers. Additional net returns over variable cost due to adoption of different CA practices in different states were found to be Rs 325–18,000 $ha^{-1}$. However, the CA practices need to be adopted selectively in different rainfall, soil and agro-ecological situations. Besides reduced tillage with mulching, other CA practices such as rainwater harvesting and recycling, appropriate soil-water conservation measures, INM, use of compost, recycling of crop residues, green manuring, crop rotation with legumes and cover crops have proved effective in enhancing the sustainability of the yields and improving soil quality across the rainfed agro-ecologies. Thus, the advantage of CA practices can be availed in rainfed agro-ecology, if practised over a long period. However, the initial investment in rainfed regions on such practices may be arranged through different on-going government schemes. Higher carbon sequestration through CA practices may also give additional benefits in terms of CERs, if made tradable in future. For promotion of CA practices across diverse agro-ecologies, appropriate technology, policy and institutional support would be a prerequisite. Strengthening delivery system at the village level is important for the adoption of any innovation. Convergence of various schemes, viz. NREGS, NHM, RKVY, NFSM, watershed programme, etc. at the local level involving all major stakeholders would surely contribute towards promotion of CA in rainfed regions. To further enrich our understanding, there is need to undertake in-depth micro-level studies on the impact of CA in different agro-climatic zones.


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